DATA SHEET

DS-10058

10kV/50A DC Power Parametric Analyzer

- **Pulses to 50A**
- **No Programming**
- **Blocking Voltages to 10kV**
- **Database Management**
- **Automatic Prober Control**
- **Integrated Production Test System [Not Just a Set of Boxes]**
- **Simple, Rugged Probe Card Interface**
- **Crosspoint Matrix to Other Instruments**
- **No Lockup with HV Avalanche Breakdown**

Overview

Reedholm has configured an integrated system, not just a set of boxes, for testing high power devices at the wafer level. Sophisticated testing, prober control, and database management do not carry a programming burden. As a result, fast, automated wafer testing is done in an inexpensive, compact probing platform.

A simple, rugged rectangular probe card interface eliminates the bulky and complicated test head that makes other testers expensive and difficult to maintain. The interface is compatible with high pressure probing that uses the Paschen relationship to reach high breakdown voltages without having to use Fluorinert.

Because the tester is based on a modern parametric tester, precise device measurements are possible, not just pass/fail or binning measurements. Crosspoint matrix connections increase the type and quality of measurements beyond what is feasible with three or four dedicated connections to cover:

- Bipolar, JFET, &MOSFET characteristics.
- High frequency (100kHz) capacitance.
- “Zero current” Rdson measurement.

Figure 1 - 50A Pulser and 10kVM Boxes

A 10kVM chuck bias box (10” long, 6” wide, 4” tall) sits behind or on top of an automatic prober. Rubber feet keep it from sliding. The bias box has a high voltage amplifier for voltage delivery and an AC/DC converter to provide power. A current pulser box with the same footprint, but only 2” high with its feet, is aligned and installed on top of the bias box. Within the boxes, 10kV/5A relays deliver voltage and current to the chuck and probe card. Separate >10kV relays provide remote, or Kelvin, sensing.

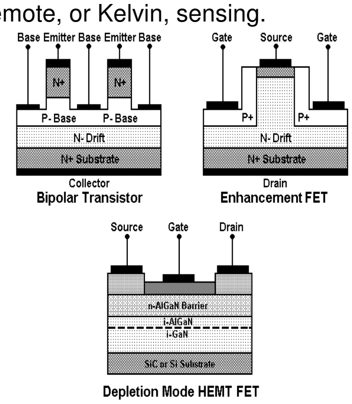


Figure 2 - Lateral & Vertical Transistors

Advantages of a Switch Matrix

Unlike lab oriented characterization instruments, special fixtures are not required for various test configurations. A cabled-in interface to a simple probe card provides Kelvin sensing to the wafer and multiple pathways. The parametric tester switching matrix and low-level instruments complement the current pulser and 10kVM options permitting low power measurements for reference.

Zero Power Channel Measurements

Figure 3 is a channel resistance sweep with Vds from 0 to 1.6mV and Ids from 0 to 190mV. Data was taken with parametric test instruments using the same probe card that delivers 50A and 10kV. Power was only a couple of hundred µW, yet linearity illustrates integrity of the 8.55mΩ data before taking measurements with the high current pulser. With the ability to take this type of data, there is no need to use an expensive piece of lab equipment to verify results.

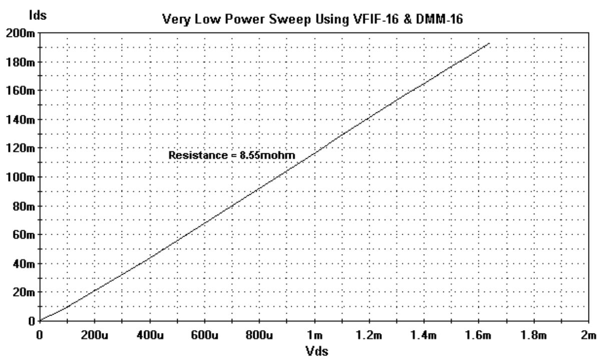


Figure 3 - Rdson with No Heating

Rdson Confirmed to 50A

After taking data without any possible self-heating, channel resistance can be measured to high currents with confidence.

Figure 4 is the sweep generated with the HIP on the same 8.55mΩ device. The small rise from 25A to 50A is due to self-heating. The small initial dip is due to an uncorrected 50mA offset error.

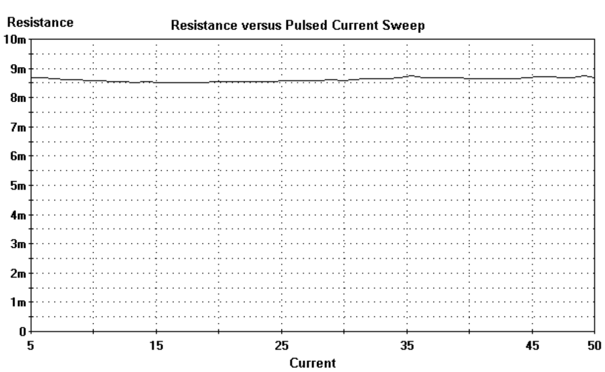


Figure 4 – Rdson from 5A to 50A

100nF High Frequency Capacitance

In addition to the gamut of DC characterization tests that can be done in conjunction with high power ones, device capacitance can be measured with the three range (1nF, 10nF, 100nF) capacitance meter. Test frequency is 100kHz with two excitation voltages: 15mV and 100mVrms.

Bias to ±250V is done through the backplane. For higher voltage operaton, Reedholm can assist with adding an HV blocking capacitor to the probe card fixturing and compensating for series capacitance.

Merging HV and Low Voltage Sweeps

Figure 5 is an example of extending 10kVM measurements down to 0V by overlaying a parametric test instrument (VFIF-16 and DMM-16) sweep with that from biasing the drain with the 10kVM option.

There is not much overlap, but it shows that starting voltage matches that taken with inherently more accurate low voltage instrumentation.

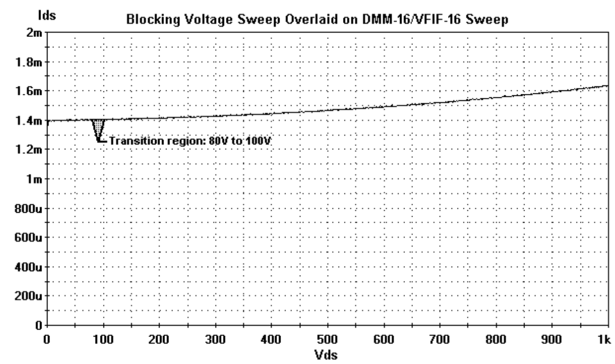


Figure 5 - Merging Low V & High V Sweeps

Protecting the Matrix and Instruments

Parametric test instruments and switching matrices are not designed to handle high voltage, so combining parametric testing with high voltage instruments means protecting lower voltage pathways.

Typical process characterization and control seldom require voltages >|100V|, or considerably less than the |600V| designed into Reedholm systems. But that is not enough to prevent high voltage arcing and discharge when signals of 1000V and more reach cables and relays designed for |600V|.

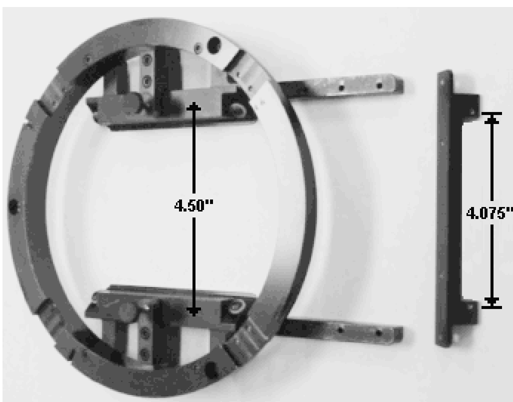
To eliminate damage to lower voltage instrumentation and cabling, 350V spark gaps are placed between the seven matrix pins and the TAC/PAC ground right at the probe card connector. These relative small devices can handle very high energies without damage. They are installed on a small pcb and the matrix cables are soldered to the end, and the pcb is soldered to the probe card edge connector.

Getting from the Lab to Production

Regardless of how much has been learned using lab equipment for development, eventually a lot of data has to be taken to be sure that they are consistent and reliable enough for customer sampling. For bench and module-based systems, that means fleshing out automatic prober control, storing/retrieving/editing test files, and bringing it all under control. With a pedigree of automated production testing, Reedholm test systems already address the gamut of automation issues.

Simple Probe Card Interface

Delivering the advantages of a matrix involves getting multiple probe pins onto the wafer. One of the simplest is with a 48-pin rectangular probe card that can be removed from the prober in whatever is most



convenient: top, front, or side. Replacing a probe card is simple. Thumbscrews are turned to loosen the clamps, the card is pulled from the connector, a different card is installed, and the screws tightened. That's far simpler than handling a massive test head.

Rich and Flexible Software

Two computers provide fast, convenient access, allowing laboratory quality measurements at production speeds. A test controller provides real-time control of instrumentation/prober operations, while operators and engineers access the system via a Windows computer running the RDS Intranet application.

No Compiling Needed

No compiling is needed to use sophisticated software to perform complex calculations in an interactive mode. RDS Intranet software provides capability well beyond what a test engineer could accomplish starting with source code.

In addition to having a rich set of test parameters stored and edited as data structures, prober control and test storage/manipulation are also data based. Because tests are data records, they are easy to copy and use for new tests.

Not a Limited Set of "Canned" Routines

"Canned" source code routines typically are limited in their ability to test many device permutations. That is why source code has to be customized. In contrast, the RDS Intranet test engine supports:

- Multiple pins per DUT leg (drain, gate, etc.).
- Biasing and grounding extra DUT pins.
- Forcing voltage or current on extra pins.
- Executing user input equations.
- Using prior test results for test conditions.

No Test Engine Ambiguity

Suspect test data is often due to improper test conditions or algorithms. With Reedholm software, algorithms are not subject to uncontrolled tweaking, so valuable time is not spent trying to work backward through code changes. Since test records are stored in a centralized and controlled database, retrieving them eliminates ambiguity over what test conditions were used. Engineers who have critical knowledge about the issue can be brought into the discussion using automatically generated test schematics without digging through source code.

Data Driven Intranet Software

High-level system operation is based on a Microsoft SQL database. Test plans, data analysis, integration with customer networks, etc. are handled with Reedholm Intranet software. A dedicated network connection to the real time test controller assures that the controller uses the right test and probing recipes. Besides a database that can be directly interrogated via SQL, Excel-compatible reports are generated in CSV and XML format.

Memory Mapped Instrument Control

A single board computer (SBC) operates under a version of MS-DOS providing real-time control without the latency issues associated with a multi-tasking operating system. As a result, timing measurements are accurate and repeatable to $<1\mu$sec without using external timer counters that complicates control without addressing latency issues.

Other system architectures have processors and memories buried inside instrumentation boxes. That approach results in slower communications and lack of control of the overall system state.

Designing for EMI Tolerance

Computer controlled instruments and probers cannot tolerate EMI created during arcing and discharge. Even if there is no permanent damage to components and cabling, loss of prober and instrument control can prevent effective system operation. How that is accomplished is covered later on.

No Compromise on Test Speed

The flat, memory mapped architecture is inherently faster than possible with bench or modular instruments, each having processors for control. Test code execution speed is faster than optimized versions of compiled code because it is so easy to change test conditions. Data driven testing is sometimes misinterpreted as using an interpreter, but that could not be further from the truth. Data is not moved or modified during software execution, so speed is the same as if data were compiled with the code.

Delays and result averaging to reduce noise are the major causes of slow testing. Those creep into compiled routines, and programming engineers never seem to have time to take them out. With Reedholm software, delays and averaging are selected after running response time plots, which only Reedholm seems to supply.

After a test plan is set up for volume testing, reports like that in figure 7 identify test speed bottlenecks. Inclusive of prober movement, test time per site was 600msec for an SIC wafer tested at 2kV.

Faster than IEEE-488 Controlled Systems

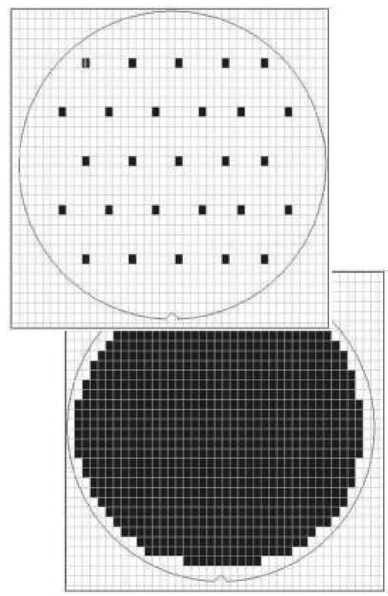
With memory mapping, complex commands are transmitted at speeds much faster than possible with IEEE-488 instrumentation buses or other serial protocols. For example, a range command is transmitted from a test plan running on the SBC to an instrument in <2µsec. As a result, Reedholm testers are inherently faster than systems that depend on older UNIX® or Linux computers, or newer multi-tasking ones.

- Software makes it simple to optimize.
- Instant results.
- Inclusive of prober movement, test time per site was 600msec for SiC parameters in figure 7.

Automatic Prober Integration

Most IEEE-488 controlled automatic probers can be, or have already been, integrated with Reedholm application software. An example of full control being valuable is illustrated in figure 8 in which wafer sampling was used for the initial wafers, followed by full mapping once yield justified the extra time. Control features include:

- Die (site) coordinate movement.
- Intradie (module or sub-die) movement.
- Multiple inkers with delayed inking.
- Off-line inking.
- Error detection and recovery.
- Material handling for wafer lot testing.
- Support of OCR and bar code readers.



Intradie	#	Test_Name	Units	Total	Min Exec	Max Exec	Avg Exec	Total Exec
M1	1	Igd current.v1	Volts	13,500	00:00:00.102	00:00:01.669	00:00:00.147	00:33:09.054
	2	GS BV at 500uA.v1	Volts	13,500	00:00:00.017	00:00:00.060	00:00:00.032	00:07:05.920
	3	Return result at 500uA.v1		13,500	00:00:00.000	00:00:00.000	00:00:00.000	00:00:00.341
	4	BVdsx: Is<1mA, Vds=1650 V.v1	Volts	12,304	00:00:00.096	00:00:00.229	00:00:00.146	00:29:56.911
	5	GS BV at 50uA.v1	Volts	13,500	00:00:00.018	00:00:00.046	00:00:00.021	00:04:42.197
	6	Return result at 50uA.v1		13,500	00:00:00.000	00:00:00.000	00:00:00.000	00:00:00.324
	7	BVdsx: Is<100uA, LotTestTimeReport;1.Test_Name (String)	[illegible]	[illegible]	00:00:00.092	00:00:00.194	00:00:00.111	00:22:11.348
	8	Rds(On).v1	Ohms	13,500	00:00:00.019	00:00:00.046	00:00:00.020	00:04:30.057
	9	Id(ON).v1	Amps	13,500	00:00:00.020	00:00:00.021	00:00:00.020	00:04:34.943
	10	Ids at Vgs=-3 V, Vds=2 V.v1	Amps	13,500	00:00:00.021	00:00:00.023	00:00:00.022	00:05:00.492
	11	Ids at Vgs=-8 V, Vds=2 V.v1	Amps	13,500	00:00:00.018	00:00:00.020	00:00:00.019	00:04:18.246
	12	Ids at Vgs=-10 V, Vds=2 V.v1	Amps	13,500	00:00:00.017	00:00:00.046	00:00:00.018	00:04:05.063
	13	Igl current.v1	Amps	13,500	00:00:00.017	00:00:00.044	00:00:00.018	00:03:59.278
	14	Vth @ Vds=10 V, Id=100uA.v1	Volts	13,500	00:00:00.041	00:00:01.238	00:00:00.046	00:10:14.582
	15	Vth @ Vds=1 V, Id=100 uA.v1	Volts	13,500	00:00:00.045	00:00:01.241	00:00:00.048	00:10:51.877
	16	Delta Vth.v1	Volts	13,500	00:00:00.000	00:00:00.028	00:00:00.000	00:00:03.004
							Total Test Time:	02:24:42.639

Figure 7 - Test Time Report from Acquire

Device Correlation with Probe Cards

Moving from three or four micro-probe needles to probe cards for volume testing is more complicated than merely putting wires on a card edge connector. Kelvin sensing is needed to deliver accurate voltages, guarded shields are needed to keep noise from overwhelming data, and the card itself needs some characterization to prevent leakage currents and breakdown paths seldom encountered with micro-probes. But volume-testing demands a probe card for quick recovery when needles are damaged or worn, etc.

Going to a probe card, and accessing other instruments for lower power measurements, isn't rocket science, but isn't trivial. Fortunately, correlating probe card results with lab data can be handled in a straightforward manner with Reedholm built-in software tools. A simple, rugged rectangular probe card interface eliminates the bulky and complicated test head that makes other testers expensive and difficult to maintain. As previously mentioned, the card is compatible with high pressure probing that prevents arcing on the surface or between needles during HV testing.

Easy to Generate Sweeps

For example, after setting up the BJT, 1kV sweep shown in figure 9, the schematic in figure 10 confirms the set-up in textbook form, and data shown in figure 11 is taken.

Drain or collector voltage is delivered to a chuck for vertical device testing up to 10kV. If topside drain/collector connections are needed, up to +3kV operation is available through the card edge connector. Higher voltage topside connections can be made on the probe card—it's just a matter of spacing.

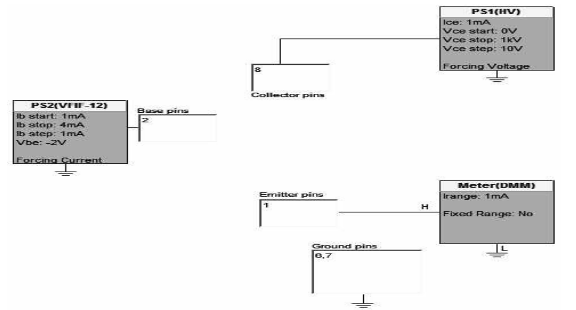


Figure 10 – BJT 1kV Vce vs Ib Schematic

Drain/Gate/Collector Curves

Varieties of sweeps can be performed. Figure 11 shows the output of an SiC MOSFET producing almost 12A at 5V. Such data can be merged with that at lower currents to cover all operating conditions.

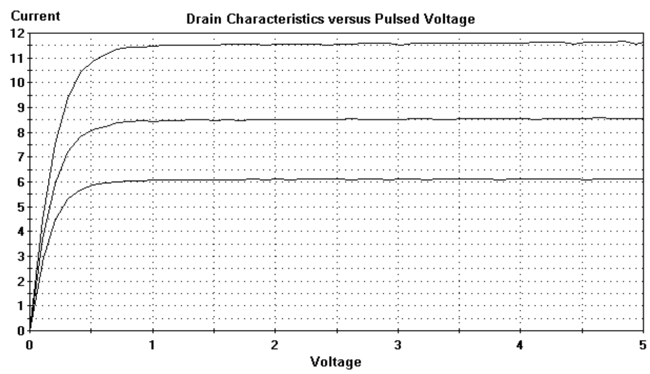


Figure 11 – Ids vs Vds Sweep

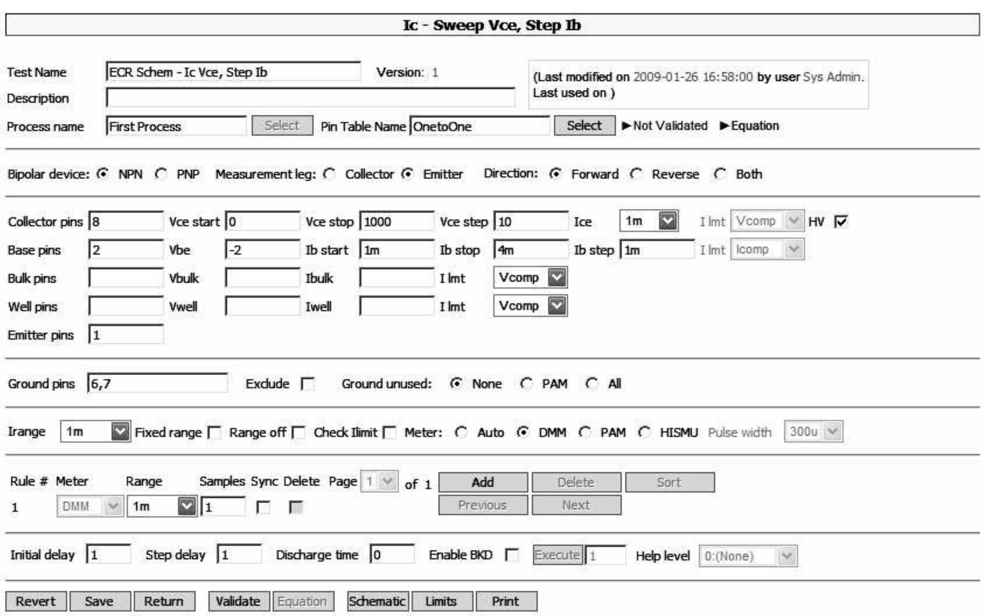


Figure 9 – Input Grid for Collector Characteristics

Pulsing to 50A

The high current pulser (HIP) option provides 50A current pulses at up to +25V for driving collectors or drains of NPN or N-channel transistors. A 2.5V range is provided for better resolution when measuring V_{cesat} and R_{dson}. Like the 10kVM, the 50A Current Pulser can be used by itself to extend a Reedholm parametric tester. It provides very high current paths for two matrix pins, nominally assigned as 7 and 8, to be delivered to the source/emitter or drain/collector terminals of the device under test. When invoked, the matrix pins are opened and the current pulser output relays are closed to provide pulses out of pin 8 and sinking into pin 7. The pulse amplifier on pin 7 can sink all of the current available from pin 8, so it acts to hold the low terminal at system analog ground. Kelvin sensing to the device under test assures that intended voltage is delivered. Deliverables include:

- A Current Pulser Box with rubber feet and secure mounting on the 10kVM box plus cabling to a system UFM.
- A UFM-CE plus cabling to deliver control voltage from PS#1, route analog pulse signals to DMM#1, and deliver digital control signals to a box containing the 50A pulsing and ground amplifiers.
- A Prober Analog Cable that delivers eight matrix paths to the probe card. From there, pins 6, 7 and 8 route to the current pulser box for gate/base, drain/collector, and source/emitter connections.

Low Resistance Measurements

One reason for this option was that the previous high current instrument (HISMU) forced vol, yet finding V_{cesat} and R_{dson} at really requires current forcing. Trying to use voltage forcing with very low impedance devices reduces loop gain and bandwidth dramatically. As a result, longer time constants prevented reaching final conditions during a pulse.

That is not an issue with the HIP. As can be seen in figure 12, forcing current eliminates settling time issues. Furthermore, figure 14 shows how stable measurements are over a wide range of currents.

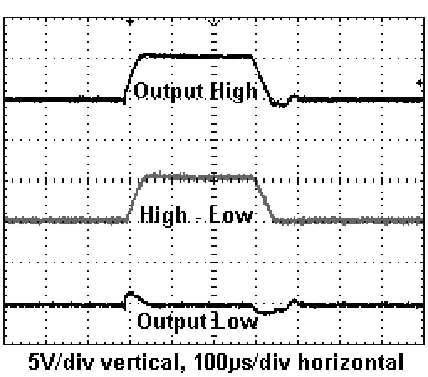


Figure 12 – 50A Pulse into 100mohm Load

HIP Box

The current pulser housing has the same width and length as the 10kV Chuck Box that the HIP option sits on, but is considerably thinner at 1.5" high. Four rubber feet rest on the 10kV box, and two posts that are added to the 10kV box protrude through the bottom of the box and the pcb. This keeps the pulser from being knocked off and essentially attaches the two instruments without use of locking hardware.

A second high current pulser is needed for bipolar transistors if base current is >200mA.

Remote Power Control

Because energy for the current pulser flows through a UFM-CE, there is no separate power control of the current pulser; it powers up and down with the instrumentation. To prevent instrument damage

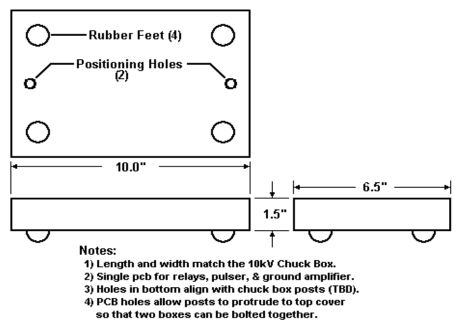


Figure 13 – Current Pulser Outline

when AC power is applied, the ±120V instrumentation supplies stay crowbarred until software control is established. When power is removed, the ±120V supplies are crowbarred within 1µsec.

On the UFM, crowbar action is made into a power enable signal that prevents HIP power amplifiers from delivering current until control is established.

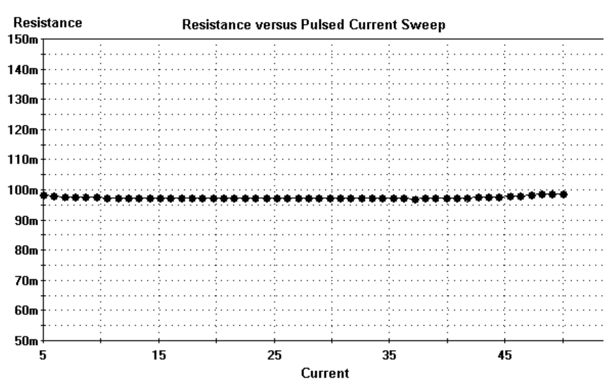


Figure 14 – Rdson Emulation from 5 to 50A

Measuring to 10kV Without Damage

Next generation SiC and GaN devices require higher voltages and currents than a previous Reedholm system, designated the RI-2kV/5A system. For instance, the 2kVM was limited to 1mA, which met the published specification needs for many devices, but did not have headroom to assure compliance. The 2kVM replacement deals with the voltage limit by going to 10kV, and the 1mA limit is addressed with 10mA compliance. Now high voltage testing can provide up to 100W at 10kV and 10mA. A 10kV high voltage box replaced the 2kV matrix that was built inline with the prober analog cable.

Voltage sensing and calibration is through a 100MΩ sensing resistor inside the 10kV box. As another example of the advantages of extending a parametric tester for HV testing, a system VFIF-16 supply and the system DMM-16 are used to to precisely measure the sense resistor, thereby allowing routine automaatic calibration of the 10kVM.

Routing Signals to the Probe Card/Wafer

When high voltage is being delivered, high voltage relays disconnect the matrix, which has ±600V standoff capability, and spark gaps prevent breakdown through the probe pins from reaching the matrix and instrumentation. Those relays also are capable of carrying high currents. Four of them in parallel pass up to 50A if the 10kVM is used in conjunction with the 50A current pulser. Deliverables include:

- A 10kVM Chuck Box with rubber feet for placement behind, or on top of, the prober with cabling to a system UFM-CE and a high current pulser.
- 10kVM calibration software to provide traceability from the 10kVM to a transfer standard bench DMM.
- A UFM-CE plus cable to deliver VFIF-16 control signals to the 10kVM and send currents to the DMM-16 for conversion to 10kVM voltage.
- A high voltage analog cable to deliver the 10kVM output to the chuck or probe card. This eliminates use of the 600V prober umbilical cable from the chuck to the side or rear of the prober.

10kVM On/Off Power Control/Protection

Fused AC power is delivered to the 10kVM box, but is withheld from the instrumentation until software initialization has been performed and the 120V reset switch has been pressed and the –120V supply has been enabled. This is essentially what is done with other Reedholm instruments to keep them from being damaged when powering up or down.

Disconnecting the cable from the UFM to the 10kVM disables power to the 10kVM. Furthermore, power is removed whenever the –120V supply is tripped.

Test Speeds

High-voltage test algorithms are based on stepped voltage ramps, with the flexibility required to assure accurate leakage current or breakdown voltage measurements. That means most tests take a few hundred msec.

However, standard algorithms do not tax the inherent speed of the option. The oscillographic output below shows the response at 10kV with no load other than the 100MΩ internal resistor. Thus, a custom test algorithm could generate a good 10kV pulse in <25msec, and repeat it within another 10msec.

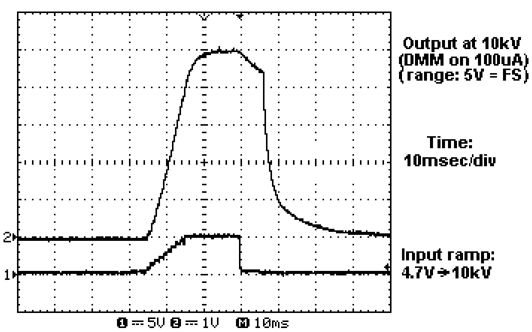


Figure 15 – Basic Response of 10kVM Option

Blocking Measurements to 10kV

Rapid non-destructive breakdown events are tough to capture, but with fine stepping of the 10kVM, the rapid increase in channel current for an SiC IGBJT was captured in figure 16.

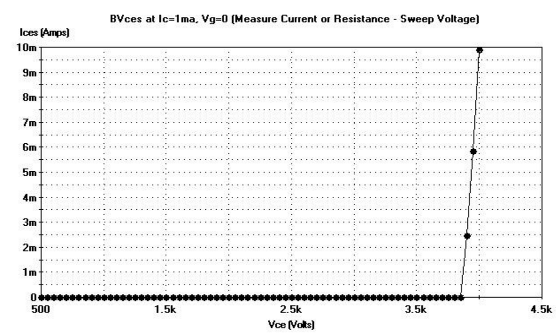


Figure 16 – Current Capture of 4kV Blocking IGBJT

Collector and Drain Sweeps to 10kV

In addition to blocking voltage tests as shown above, collector and drain characteristic curves can be generated at currents up to 10mA and 10kV, with assurance of breakdown detection and recovery.

Keeping Control at Breakdown

Since unpredictable device breakdown can occur at any time, software and hardware modifications are made to the instruments and prober to prevent loss of control during catastrophic breakdown. For instance, system instruments can be damaged and the prober can drive the chuck into the probe card, with destruction of the wafer along with the probe card.

Memory Mapped Detection & Recovery

Memory mapped instrumentation is a major reason for being able to achieve such control. Reedholm does not assemble a bunch of instruments that have to be controlled through a complex bus with latency issues. Instead, instrument actions are the result of memory transactions in a dedicated, single tasking test controller.

Map Contents

The map in figure 17 is of the base instrument group, comprised of 12, 8-pin matrix modules, six programmable supplies, two differential DMM/s, a capacitance meter, four user function modules, a self-calibration unit, two pulse generators, etc. Each two character location corresponds to 8 bits, so the 16 x 16 array displays the contents of 256, 8 bit, registers.

State Capture

The entire system state is captured prior to each transaction, including delay times to wait for instrument settling, that might lead to catastrophic breakdown. That state is then compared to the state after the transaction.

Any non-controlled disturbance to the map is evidence of imminent loss of control, so the memory registers are put back into the previous condition followed by controlled power down.

Continual Checking for Changes

The map can be acquired much faster than relays can open or closed. Thus, unplanned state changes or disturbances are rectified before relays can react. That eliminates relay and instrument damage due to hot switching. As a result, high voltage testing does not lead to periodic instrument damage as it does in most lab systems.

Minimizing EMI with 100kΩ Rout

Years ago during development of the 1.5kV extension used for thick oxide breakdown testing, a 100kΩ resistor was added to minimize EMI and allow continued operation despite catastrophic breakdown events. That same size works with the 10kVM once a ferrite inductor is added to the output and to the grounding resistor. Slow down of initial breakdown prevented scrambling. Also, discharging the output through a 1MΩ resistor did not cause scrambling.

Correction for 100kΩ Rout

Drain or collector voltage is corrected for voltage drop across the output resistance so that 10mA measurements can be made above 250V. In such a cases, the 10kV regulator outputs additional voltage equal to the output current times 100kΩ.

- Current at a Voltage tests iterate to a final voltage using the measured current to adjust output voltage at each step within ±10V.
- Voltage at a Current tests have slightly higher and lower start and end points since voltages do not need to be iterated during the search.
- Drain and Collector sweeps start near 0V, and thus 0A, so corrections are small to start with. At each point, actual corrected voltage is paired with each measured current.

• Low field (Vcesat and Vdson), Gummel plots, etc. are run with low voltage instruments, so compensation is not needed for them.

```
**********************************************************************
 Instrumentation Memory Map:    MemBase =       Group = 0
**********************************************************************
2nd Adx Char ---->   0  1  2  3  4  5  6  7    8  9  A  B  C  D  E  F
1st Adx Char -> 0   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00
1st Adx Char -> 1   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00
1st Adx Char -> 2   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00
1st Adx Char -> 3   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00
1st Adx Char -> 4   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00
1st Adx Char -> 5   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00
1st Adx Char -> 6   48 01 7F F7 10 02 FF 00   20 01 7F F7 10 02 FF 00
1st Adx Char -> 7   4C 01 7F F7 10 02 FF 00   5F 01 7F F7 04 00 00 00
1st Adx Char -> 8   00 29 7D 00 00 00 01 00   00 42 00 00 20 00 01 00
1st Adx Char -> 9   00 18 00 00 00 00 00 00   73 21 7F FF 00 5C 6C 00
1st Adx Char -> A   50 54 45 54 2E 4F 3B 00   00 00 00 00 00 00 00 00
1st Adx Char -> B   3B 04 7F F7 10 00 00 00   57 04 7F FF 04 00 00 00
1st Adx Char -> C   00 84 00 00 00 00 00 00   00 84 00 00 00 00 00 00
1st Adx Char -> D   00 84 00 00 00 00 00 00   00 84 00 00 00 00 00 00
1st Adx Char -> E   00 00 00 00 00 00 00 00   00 7F FF 00 00 00 03 30
1st Adx Char -> F   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 38
```

Figure 17 - Instrumentation Memory Map

Assuring Accuracy

Reedholm parametric testers do not require expensive, custom fixtures to assure accuracy or trace system accuracy to a standards lab. Starting with direct measurements using an external bench DMM, the flow-chart in figure 18 illustrates how the self-calibration module (SCM-BP, 11106) provides an easy, cost-effective method to make Reedholm instrumentation agree with any standards lab.

Using a software utility called SCal, an external DMM is brought to the system, and a small set of DC and resistance measurements are entered into a text data file. That file is subsequently used by another package called SelfCal to find the gain correction factors that make the internal system DMM-16 exactly match the standards lab DMM. After measuring current and voltage offsets, the internal DMM is used to calibrate every DC instrument in the system.

As a result of those measurements, every DC value, forced or measured, in a Reedholm system is directly traced to the standards lab DMM.

Set and Forget Adjustments

Running the self-calibration programs eliminates the need to do manual calibration. All potentiometers thus are “set and forget” adjustments done at the factory when modules are built or repaired.

Automatic Calibration at Any Time

Self-calibration can be performed at any time, as long as no external connections are made to the prober analog cable. That can usually be accomplished by dropping the chuck away from the wafer.

Extending to 50A and 10kV

With the DMM-16 and VFIF-16 modules calibrated, their accuracy is extended to the 50A and 10kVM options by making precision measurements and calculating correction factors. Figure 19 compiles content of several traceable calibration file printouts.

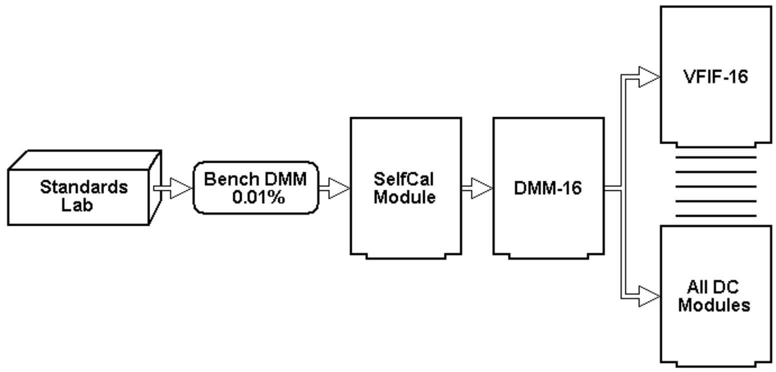


Figure 18 – Accuracy Traced from Standards Lab

Automatic 10kVM Calibration

For the 10kVM, lower voltage instruments are used to measure the 100MΩ output sense resistor, followed by measurements of cardinal output voltages including the maximum that the user plans on.

Automatic 50A Pulser Calibration

Automatic calibration of the 50A pulser is more complicated, involving current and voltage correction factors in both forcing and measurement modes. Current forcing/measuring accuracy is based on measurement of an on-board, stable, 4-T resistor with the Reedholm VFIF-16 and DMM-16.

```
Operator----------------> [Tech1234]
Tester ID---------------> [REEDHOLM]
Prior SCAL Temperature-> [ 26.93]
Measured Temperature---> [ 28.46]

VOLTAGES ENTERED:
Range          Positive        Negative
-------     -----------     ------------
  250mV          243.91m         -244.86m
  500mV          488.31m         -489.28m
     1V          977.11m         -978.13m
   2.5V          2.4455          -2.4465
     5V          4.8913          -4.8925
    10V          9.7832          -9.7848
    25V           24.68          -24.681
    50V          49.357          -49.361
   100V          98.716          -98.724

RESISTANCES ENTERED:
Range         Actual
-------    -----------
   10K        10.0012k
   10M        10.0044M
```

```
                           DMM #1 (DMM16)
           Measured Value                 Cal Test Limits
Range   Gain Factor    Offset        Gain Factor      Offset
-----   -----------  ----------     -----------    ----------
250mV            1   -3.60649u     1.0 ±0.0009          850u
500mV      1 00009   -1.06684u     1 0 ±0.0009          850u
   1V      1.00008   -9.25226u     1.0 ±0.0009          900u
 2.5V            1   -56.1744u     1.0 ±0.0009          1.1m
   5V      1.00002   -85.4418u     1.0 ±0.0009          1.6m
  10V            1    -158.61u     1 0 ±0.0009          2 6m
  25V            1   -1.29106m     1.0 ±0.0009          5 6m
  50V      1.00001   -1.60026m     1.0 ±0.0009         10.6m
 100V     999.987m   -2.70015m     1.0 ±0.0009         20.6m
```

```
                           DMM #1 (DMM16)
           Measured Value                 Cal Test Limits
Range   Gain Factor    Offset        Gain Factor      Offset
-----   -----------  ----------     -----------    ----------
100nA      999.12m   -6.27454p     1.0 ±0.0052          275p
  1uA     999.674m   -43.7783p     1.0 ±0.0045          465p
 10uA      999.68m   -422.016p     1.0 ±0.0023          3.5n
100uA     999.886m   -3.68202n     1.0 ±0.0013           35n
  1mA            1   -20.6759n     1.0 ±0.0013          350n
 10mA     999.872m   -202.039n     1.0 ±0.0013          3.5u
100mA     999.938m   -1.66163u     1.0 ±0.0023           35u
   1A      1.00029    -15.861u     1.0 ±0.0023          350u
```

```
 HV CALIBRATION RESULTS
 -----------------------------------

 CALIBRATION DATA

   Vout offset          = -113.927
   Transfer function    =  2.11053k
   Calibration resistor =  99.7356M
```

```
Measuring 100M sense resistor (10s)..Done.

R = 99.7356M, Ical = 952.391n, Ioff =-126.176p
Measuring HV outputs...Done.
Powering down HV unit...Done.
HV readings: HV out=  1k     PSout=  468.625m  Imeas=  8.79909u
HV readings: HV out=  4.25k  PSout=  1.99165   Imeas=  40.9545u
HV readings: HV out=  7.5k   PSout=  3.51469   Imeas=  73.2578u

10kVM Pwrdwn time= 5.00005 s. Vout= 44.2576
```

Figure 19 – Self-Calibration Data Including SCM-BP, DMM-16, and 10kVM

Adding the 50A and 10kV Options

10kVM Chuck Box

The 10kVM block diagram in figure 20 shows the critical components except for TAC/PAC connections to the probe card. Those are shown in figure 22 later in this document.

- VFIF-16 sets output voltage and controls relays with multi-level negative voltages.
- 2nd VFIF-16 biases sense resistor when calibrating.
- DMM-16 measures output through 100MΩ sense resistor after calibrating with PS2.
- UFM-CE connects PS1, the control VFIF, and the DMM for testing and calibration.

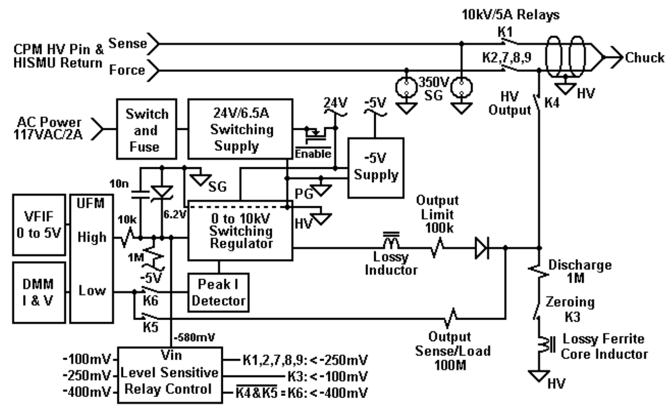


Figure 20 – 10kVM Block Diagram

High Current Pulser (HIP)

The pulser block diagram in figure 21 is not as complete as the 10kVM one, but shows more functional details.

- A UFM-CE is dedicated to the HIP, connecting a VFIF-16 and DMM-16 to the HIP box. Digital signals from the UFM-CE control the pulser state and output relays.
- Current compliance and voltage pulse height are multiplexed into the HIP box from PS1.
- Multiplexed output voltages digitized by the DMM-16 are converted to output voltage and current.
- Calibration is performed to 10A & 20V using PS1, the DMM, and the reference resistor.
- Multiple matrix relays each handle 10A pulses, or 3.3A per reed switch, with pulses <500µsec and duty cycles <1%.
- The pulsing amplifier can force 50A total, into the drain or collector of a test device.
- The ground amplifier in the pulser box must sink >50A in order to handle, emitter current , the sum of base and collector currents.
- Three cables attach to the HIP:
  > Power, node, and digital signals from UFM.
  > Drain/collector signals to/from the 10kVM.
  > Source/emitter signals to/from a probe card.

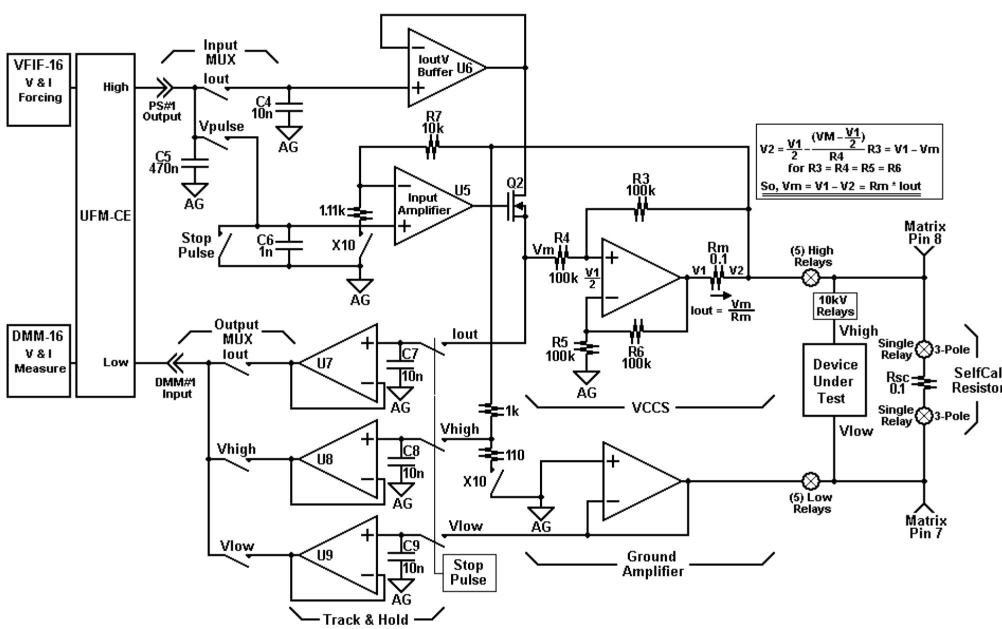


Figure 21 – HIP Block Diagram

Extending to the Wafer

The high voltage and high current capabilities are extensions of the parametric test instruments, so voltages to 10kV and currents to 50A are delivered with traceability to NIST or other standards.

- High voltage can be delivered in <50msec with uncertainty <|0.5%| and no overshoot.
- Current pulses from 100µsec to 25msec and up to 50A (25mC maximum) wide can be delivered at 1% duty cycle. Maximum pulsewidth at 50A is 100µsec.

Drain or collector voltage can be delivered to the chuck for vertical device testing up to 10kV. If top-side drain/collector connections are needed, Reedholm assists with assuring up to +3kV operation through the card edge connector on the prober analog cable. Higher voltage top-side connections can be made directly at the probe card.

The block diagram at the bottom of the page shows those probe card cable assignments and how standard Reedholm instrumentation is extended to provide higher power, all without losing the advantages of the precise instruments.

Short Cables for Pulse and EMI Control

Cable lengths are kept short for performance. High rates of current change between the extended instruments and the probe card lead to voltage errors and overshoot calculated from V = LdI/dT. Short cables minimize self-inductance.

On the other hand, accurate delivery of high voltage does not require benefit from short cables. However, energy storage is proportional to CV^2, so short cables, which minimize stray capacitance, minimize EMI generated at device rupture.

EG2001: 10kV Tolerant Prober

Unless another supplier of probers that can tolerate high-energy breakdown pulses is available, a 10kV breakdown-ready prober from EMTS, based in New Hampshire, should be purchased and sent to Reedholm for integration.

Having the Reedholm instrumentation built into the left-hand bay of a high table EG2001 prober minimizes system footprint. And the EG2001 prober hardware is modified to ignore EMI spawned by catastrophic device breakdown, a constant threat to instrumentation and probers.

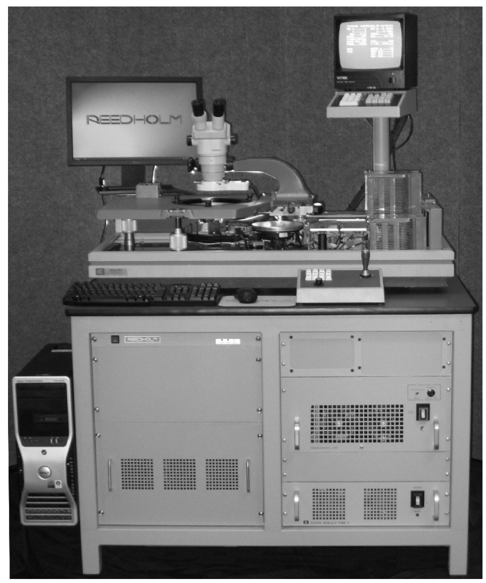


Figure 23 – EG2001 with Material Handling

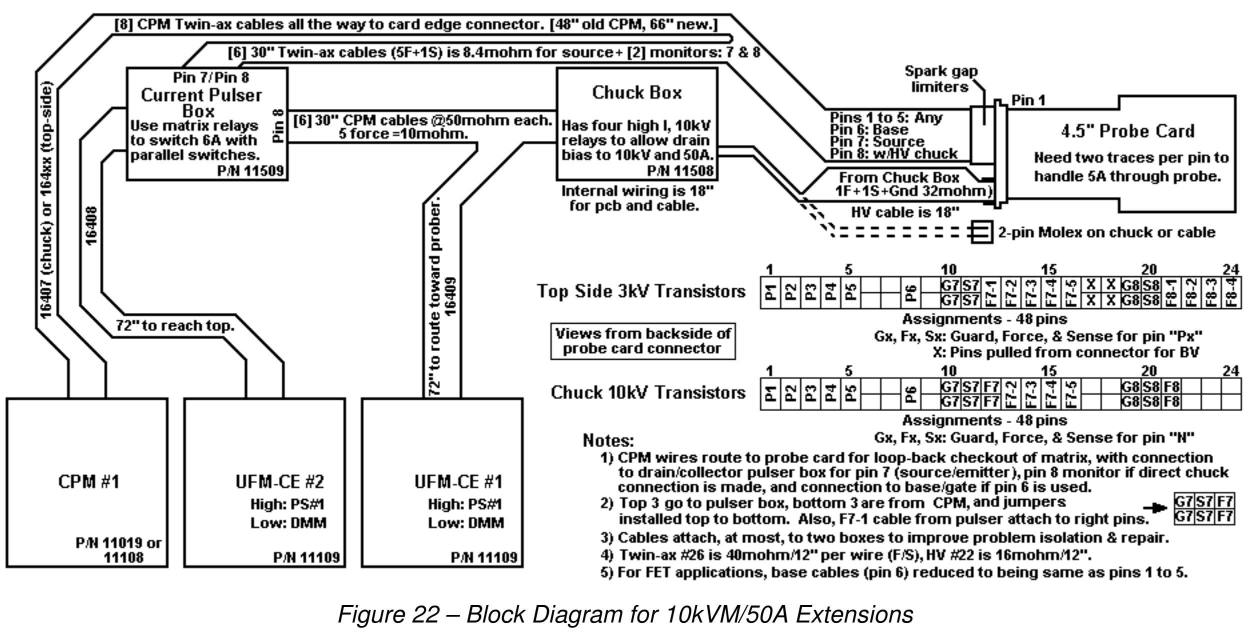


Figure 22 – Block Diagram for 10kVM/50A Extensions

Comprehensive Training and Support

There are obvious benefits of buying a tool that is ready for volume testing—it shortens time to customer deliveries and maximizes engineering productivity.

Not so obvious are the benefits of outsourcing the work to making the test system supportable. When building a system from bench or modular instruments, it is rare for a company to put the support structure in place for production use. Fortunately, Reedholm is in the business of supporting production test systems.

Obsolescence Eliminated

Reedholm does not practice planned obsolescence. Instrument designs are continually upgraded, and replaced only when components are no longer available. Applications software generally operates with the oldest designs.

When modules are sent to Reedholm for repair or checkout, they are first upgraded to latest design level before troubleshooting using the latest released software. Customers benefit by getting the latest hardware version back, and Reedholm doesn't waste time working on problems that have already been solved with hardware or software changes.

It isn't necessary to wait for a module to fail to get it upgraded. At any time, customers can have modules upgraded to the latest level for a modest fee.

Acceptance and User Training

System performance to specifications is done at Reedholm before shipment. In addition, customers are encouraged to run correlation wafers so that system or training issues can be handled before shipment.

A prime objective of system training is to have users ready to populate test plans and set up probing patterns by the end of the course. While system training can be done on-site at an additional charge, doing it at Reedholm minimizes interruptions and maximizes learning. User training covers:

- Building test plans and probe patterns.
- Device characterization and optimizing test results/speed.
- Data analysis and database maintenance.
- Basic system maintenance.

Real-Time Hands-on Assistance

Applications assistance is provided via the Internet using GoToMyPC software. With it, Reedholm engineers can control a system anywhere in the world to:

- Run maintenance programs.
- Troubleshoot device test issues.
- Apply software patches.

In addition, telephone, fax, and e-mail support is available from the U.S. Monday through Friday, excluding holidays at:

- Phone: 1-512-876-2268
- Email: support@reedholm.com

Local technical support from Reedholm distributors is available in many parts of the world.

Documentation

After the system is installed, on-line user manuals describe instrumentation and application software operation down to the bit level. The manuals can also be accessed on the installation CD for those rare circumstances when the application does not start.

Warranty

Warranty is 12–months for defective parts and labor with work performed at the Reedholm Texas facility. For remote facilities that cannot make effective use of overnight shipping, a set of spares is an economical solution to keeping systems on-line. Spares also reduce downtime if custom agents have to get involved with shipments.

Service Contracts

After the warranty period, service contracts are provided at modest annual costs, with fees applicable to repairs and on-site support. Once the annual fee is used up, repairs and service are available at published rates.

Scope of Specifications

Unless Reedholm probe cards are used, instrument specifications apply to the end of a 41" prober analog cable (PAC) with no probe card attached.

With Reedholm probe cards, performance is guaranteed with Reedholm blade mounting.

Facility Requirements

Nominal system power is 117V±10% at 50 or 60Hz and 15A for the instrumentation cabinet, 10kVM, 50A current pulser, test controller, and test station monitor. Regulated system supplies isolate instrumentation from power line variations. Operation at other voltages requires external power transformers. For instance, step-up transformers are typically used in Japan, and step-down ones in Europe.

Additional computers and peripherals generally have built-in ±10% tolerance for power line variation, and can operate at 50 or 60Hz.

Environmental Conditions

Warranty only applies for these conditions:

- Temperature: 18° to 28°C
- Humidity: 10% to 50% R.H. non-condensing

Switching System Specifications

The switching sub-system is a critical element in dc parametric testing. Reedholm has developed well guarded, low noise, low thermal crosspoint switching modules using dry reed relays.

Inherent long relay lifetimes are assured by elimination of hot switching (i.e., opening or closing relays when there is enough energy available to cause material transfer between switch contacts).

The same class of relays and the same layout rules are used for all modules that plug into the instrument backplane, so these specifications apply to the user function interface (UFM) as well as the CPM, PAM, and node switches on function modules.

Switching Parameters	Limit
Maximum stand-off voltage	±600V
Maximum carrying current	±2A
Pin leakage with ±100V on all other pins	<±10pA*(# of pins)
Pin-to-pin thermal emf	<±100µV
Shorted pin-to-pin resistance	<500mΩ
Switching speed including delays	1ms

High Current Pulser Specifications

V/I Forcing/Measuring Parameters				
Pulse Mode	Function	Error		Resolution
		Offset	% of Value	
Current	Force / Measure	21.2mA	0.58	1.5625mA
Voltage 2.5&25V Ranges	Force	250µV/2.5mV	0.017	78µV/780µV
	Measure	2mV/20mV	0.28	

Pulse Parameters		
Pulse Width	Minimum	100µsec
	Maximum	25msec or 500µsec*50A/Iforce, whichever is greater.
	Resolution	1µsec
	Accuracy	Same as resolution
Pulse Period	Minimum	100msec
	Maximum	Unlimited
Pulse Delay	Minimum	1msec
	Maximum	Unlimited
	Resolution	1msec
Rise & Fall Times	Voltage mode	<10µsec, exponential
	Current mode	<47µsec, linear

Comments:

1. Offset and gain factor (% of value) errors apply after running HIP calibration and system SelfCal.
2. The two voltage ranges, 2.5V and 25V, have corresponding offset terms and resolution that also have a 10:1 ratio.
3. Voltage mode rise time is for linear operation with Idevice < Iforce.
4. Current mode rise time is for Vout at the HIP < Vforce.
5. The HIP can be used in most Reedholm test systems with appropriate analog prober cabling, a UFM-CE, a 10kVM chuck box, and cabling.

10kVM Specifications

Mode	Range	Measure Error			Resolution
		Vcurrent	Offset	% of Value	
Voltage	10kV	5kΩ*Iout	2.5	0.084	312.5mV

Comments:

1. Offset and gain factor (% of value) errors apply after running 10kVM calibration and system self-calibration.
2. Voltage noise is 6V peak-to-peak over a 20MHz bandwidth.
3. Dominant time constant is <10msec, so with custom code, ramping takes <50msec to be within 1%, and <70msec within 0.1% of final value.
4. A/D conversion is performed by DMM-16 in <50µsec without averaging.

100kHz CMM Specifications

Range (pF)	Source Error		Resolution (fF)
	Offset(1,2)	% of Value	
100	0.01% of Range	0.02	3.5
1000			35
10000		0.03	350

Comments:

1. Repeatability is within ± 0.01% for stable external conditions.
2. Offset errors based on use of offset compensation.
3. % of value errors are relative to calibration capacitors and include effects of prober analog cable.
4. Measurement accuracy is proportional to range offset error and percentage of value measured. For example, measuring 50pF on the 100pF range results in ±20fF uncertainty span

   C_x = 50pF ± (0.01% of 100pF + 0.02% of 50pF)
   C_x = 50pF ± (10fF + 10fF)
   C_x = 50pF ± 20fF
5. DC voltage biasing to ± 600V has no effect on accuracy.
6. Test frequency is 100kHz ± 0.01%.
7. Test levels are selectable at 15mV or 100mV rms ± 1.0%.
8. Step response to within 0.1% of capacitance change is <2msec.
9. A/D conversions are 50msec.

VFIF-16 Specifications

Mode	Range	Source Error		Resolution
		Offset	% of Value	
Voltage	2.5V	500µV [100µV]	0.014	78.125µV
	5V	1mV [200µV]		156.25µV
	10V	2mV [400µV]		312.5µV
	25V	5mV [1mV]		781.25µV
	50V	10mV [2mV]		1.5625mV
	100V	20mV [4mV]		3.125mV
Current	100nA	200pA	0.04	1.5625pA
	1µA	700pA	0.02	15.625pA
	10µA	2nA [700pA]		156.25pA
	100µA	20nA [6nA]		1.5625nA
	1mA	200nA [60nA]		15.625nA
	10mA	2µA [600nA]		156.25nA
	100mA	20µA [6µA]	0.04	1.5625µA
	1A	200µA [60µA]	0.05	15.625µA

Comments:

1. Maximum output current is 200mA on the 1A range.
2. Accuracy on lowest two current ranges requires line cycle integration.
3. Offset errors shown in brackets [ ] are for an 8-hour period and ±1C°.

DMM-16 Specifications

Mode	Range	Measure Error		Resolution
		Offset	% of Value	
Voltage	250mV	250µV [50µV]	0.05	7.8125µV
	500mV	250µV [50µV]	0.03	15.625µV
	1V	300µV [75µV]	0.02	31.25µV
	2.5V	500µV [100µV]	0.01	78.125µV
	5V	1mV [200µV]		156.25µV
	10V	2mV [400µV]		312.5µV
	25V	5mV [1mV]		781.25µV
	50V	10mV [2mV]		1.5625mV
	100V	20mV [4mV]		3.125mV
Current	100nA	100pA*	0.04	3.125pA
	1µA	300pA*	0.02	31.25pA
	10µA	2nA*		312.5pA
	100µA	20nA		3.125nA
	1mA	200nA		31.25nA
	10mA	2µA		312.5nA
	100mA	20µA	0.04	3.125µA
	1A	200µA	0.05	31.25µA

Comments:

1. Settling time to 0.01%:
   4.0ms, 100nA Range
   2.3ms, 1µA Range
   1.7ms, 10µA-1A Ranges
   1.6ms, 250mV-100V Ranges
2. Accuracy is determined with digital averaging approximating AC power line cycle integration.
3. Offset error shown in brackets [ ] are for an 8-hour period after auto zero, and for ±1C°.
4. When measuring current from sources with non-zero output conductance, add the following amounts to the error specification: ±(830ppm of value + 151pA)/mho.

EMTS EG2001 Prober Modifications

EMTS extensively modifies an EG2001 prober for >10kV operation and arranges for installation at Reedholm for full system integration and customer acceptance.

- Stainless steel sheet metal is placed on top of the prober table and tied to the prober power line ground.
- Braided ground straps are added several places to the body of the prober.
- TTL-based control boards are replaced with newer, but less noise sensitive, CMOS-based boards.
- Sensitive one-shot circuits are modified to increase EMI tolerance without affecting overall prober operation or speed.
- Arcing between the chuck top and various metallic elements is prevented with longer inserts and some plastic fixtures replacing metal ones.

Reedholm HV Chuck Cable

Instead of the standard EG twin-axial analog chuck cable, Reedholm installs a custom Kelvin cable built from 18kV non-corona wire shielded by a braided shroud. An a tough, shrink wrapped outer layer insulates the braided stroud.

To minimize coupling to prober electronics, the cable is not routed through, or near, the umbilical cabling from the rear of the prober to the chuck. Instead, it is attached to the chuck via a two-pin, Molex connector capable of carrying >50A. The cable is light and does not restrict movement or speed of the forcer motor moving the chuck.

The Reedholm HV cable can be modified for attachment to the chuck or probe card connector if a prober other than the EG2001 is used. It would deliver HV and high current pulses to published specifications. The prober needs to be immune to catastrophic device breakdown whether HV connections are made to the back or topside.